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Microbial Sampling Variables and Recreational Water Quality Standards

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Abstract: A study was conducted at two beaches on Lake Erie to evaluate the water sampling design for the collection of several microbiological indicator organisms in relation to day, time, and location of collection. The concentrations of these organisms were generally found to vary significantly ($P < 0.05$) by the specific time of day and day of weekend that collection took place. However, the concentrations of these organisms did not vary significantly ($P > 0.05$) at various locations in the bathing area. Future studies investigating the health effects of recreational water as related to microbiological variables should be designed to collect water samples at the specific time of day and day of weekend that an individual was exposed. In addition, sampling at various locations in the bathing area should probably be considered for those beaches having poor dispersion of fecal waste sources. (*Am J Public Health* 1981; 71:283-289.)

Introduction

There are tremendous variations in water quality standards used for bathing in recreational waters because of the paucity of relevant epidemiological information upon which to base a standard. In 1944, all United States Bathing Water Quality Standards were based on total coliform counts ranging from 50 to 2,400 coliforms/100 ml of sample.[1] The disparity between total coliform counts for these standards is even more prominent in the case of international standards. For example, England and Wales use a standard of 10,000 coliforms/100 ml; Japan uses 50,000 coliforms/100 ml; while Australia and South Africa have no standards.[2] Numerous documents show the great variability in total coliform counts used as standards for bathing water quality.[3-7]

Total coliform bacteria concentrations have generally been replaced by fecal coliform bacteria concentrations as an indicator of bathing water quality. The reason for this change was that total coliform bacteria include coliforms of both fecal and nonfecal (naturally occurring) origin. The nonfecal organisms are of limited sanitary significance since they are not pathogens for men or animals and are capable of excessive growth in fecal waste.

Although fecal coliform bacteria in the environment are indicators of animal fecal contamination,[8] the fecal coliform counts employed in the US and its territories for bathing water quality standards are variable. For instance, fecal coliform standards for beaches vary from 70 to 1000/100 ml of sample in the US.[9] The most common count used for bathing waters is 200 fecal coliforms/100 ml sample and is based on a total coliform to fecal coliform ratio of 5:1.[10] There is no scientific justification for maintaining that recreational waters with less than a total coliform count of 1,000 with 20 per cent fecal coliforms are safe for bathing. Nevertheless, in 1968 the National Technical Advisory Committee (NTAC) to the Federal Water Pollution Control Administration recommended that ". . . the fecal coliform content of recreation waters shall not exceed a log mean of 200/100 ml, nor shall more than 10 per cent of total samples during any 30 day period exceed 400/100 ml."[11] Geldreich supported the above standard when he stated that fecal coliforms have been assessed and reassessed as indicators of pollution in recreational waters and felt that 200 fecal coliforms/100 ml for bathing beaches is both realistic and consistent with laboratory and field investigations.[8]

Several bacteriological surveys of recreational waters have been conducted with the primary objective of determining water quality changes and safety for use.[12-16] All of these studies were successful in demonstrating fecal contamination of these various recreational waters at one time or another. However, they were not able to establish a critical minimum total coliform, fecal coliform, fecal streptococci, or salmonella concentration that would be safe for human contact.

There have been several epidemiological studies that have attempted to assess incidence of illness with bathing in waters with fecal contamination.[17-22] Although these studies have indicated that many different types of bathing related illnesses may be acquired through contact with or ingestion of recreational water, it is unlikely that one bacterial indicator such as fecal coliforms will sentinal all health hazards related to recreational waters. Additional indicator organisms other than fecal coliforms have been suggested for bathing standards. Such organisms as Staphylococci,[23] Streptococci and Clostridia,[24] and *Pseudomonas aerugi-*

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nosa[25,26] are but a few of the possible indicators of health hazards for recreational waters. Furthermore, if a water quality indicator is going to be used to determine the health risk of bathing in recreational waters, the water sampling design for the collection of microbiological indicator organisms is most important. This study evaluates the concentration of several microbiological indicator organisms in relation to day, time, and location of collection at two beaches on Lake Erie.

Materials and Methods

Two beaches in the Cleveland, Ohio metropolitan area on Lake Erie were chosen for this study. One beach, Edgewater, is located in the city of Cleveland on the west side. It has 250 meters of shoreline and is situated near two major point sources of organic and inorganic pollution that contribute high concentrations of fecal coliforms at the beach. One source of the pollution comes from the wastewater treatment plant located approximately 1,600 meters east of the beach. At the time of this study, the influent at the treatment plant was only receiving primary treatment. The second point source of fecal coliform contamination results from two storm sewers located approximately 300 and 3,000 meters west of the beach. The monthly geometric mean fecal coliform concentrations at Edgewater Beach consistently exceed the Ohio Department of Health standard of 200 coliforms/100 ml sample based on not less than five samples per month. Even though the Cleveland Department of Health has posted Edgewater Beach as "unsafe for swimming," people still use the beach for bathing. As a consequence, life guards still monitor swimming activities at this beach.

Headlands State Park, located approximately 40 kilometers east of the city of Cleveland near Mentor, Ohio, is the other beach utilized in this pilot study. This beach, with its 600 meters of shoreline, has monthly geometric mean fecal coliform concentrations well below the state standard. No wastewater treatment plants, storm sewers, or other point sources of fecal coliforms were found in the vicinity of this beach. In fact, a water treatment plant is located approximately 100 meters west of the beach.

Five samples were collected at each beach at 0900, 1200, and 1500 hours on both Saturday and Sunday for three consecutive weekends starting July 16, 1977. All samples were collected 10 centimeters below the water surface. One sample was taken in knee depth water off the center life guard stand; three samples were taken horizontally across the bathing area at chest depth (one off of the center life guard stand, one each in the easterly-most and westerly-most direction that swimming was allowed; and one sample was taken at the furthest point out that swimming was allowed off the center life guard stand.) All samples were collected, stored, and analyzed within time constraints as defined in *Standard Methods for the Examination of Water and Wastewater*.[27]

Analysis of Water Samples

Each of the collected water samples was analyzed for total coliforms, fecal coliforms, *E. coli*, fecal streptococci, *P. aeruginosa*, and total staphylococci. The analysis of total coliforms was done in accordance with *Standard Methods*.[27] The samples were filtered through 0.45 μm Gelman Filters and incubated in a Thelco Model 6M incubator for 18 hours at 35° C on M-Endo Broth. The colonies exhibiting a metallic green sheen were counted for the total coliform number.

Fecal coliforms and *E. coli* analyses were done using a technique developed by DeFour, *et al*.[28] In general, samples filtered through 0.45 μm Gelman Filters were incubated in a Thelco Model 6M incubator for two hours at 35° C on a TEC Media. After two hours, the plates were transferred to a Blue M Magni-Whirl Water Bath and incubated for 20 hours at 44.5° C. After incubation, all yellow colonies were counted as fecal coliforms. After the fecal coliforms were counted, the membranes were transferred to a sterile pad saturated with urea substrate for 15 minutes, and then these yellow colonies were counted as thermotolerent *E. coli*.

For the determination of fecal streptococci, E and EIA media were used as directed by Levin, *et al*.[29] The filtered samples on the 0.45 μm Gelman Filters were first placed on E media and incubated in a Blue M Magni-Whirl Water Bath at 41.5° C for 48 hours. After the incubation period, the membranes were transferred to EIA media and incubated for 20 minutes at 41.5° C. The colonies showing a black precipitation on EIA media were counted as fecal streptococci.

The analysis of *P. aeruginosa* was done in accordance with *Standard Methods for the Examination of Water and Wastewater*[27] supplemented as directed in an article by Levin and Cabelli.[30] The filtered samples on the 0.45 μM Gelman Filters were placed on mPA Agar and incubated in a Blue M Magni-Whirl Water Bath at 41.5° C for 48 hours. Colonies which were brownish to metallic black were counted as *P. aeruginosa*.

Total staphylococci were enumerated on the 0.45 μm Gelman Filters on Champmone Stone Agar.[27] The prepared plates were incubated in a Thelmo Model GM Incubator for 48 hours at 35° C. All colonies except those which were mucoid or rough were counted as total staphylococci.

All of the above microbiological data were reported as number of colonies per 100 ml of sample. Three people counted the colonies from all of the samples. Internal controls were incorporated to check on the accuracy of counting.

Results and Discussion

Concentrations for total coliforms, fecal coliforms, *E. coli*, fecal streptococci, *P. aeruginosa*, and total staphylococci, obtained from water samples collected at Edgewater and Headlands beaches, have been averaged for the three weekend collection periods. The mean concentrations for these microbiological organisms are given in Tables 1-6 by beach designation, time and location of collection, and day of weekend.*

*Data for each of the three weekend collection periods are available on request to author.

Each of the microbiological concentrations was analyzed statistically with a four-factor analysis of variance (ANOVA) in conjunction with the Scheffé multiple comparison technique[31] in order to detect any significant aberrant patterns in the concentrations by day, time, location, and weekend of collection. The analyses of the microbiological data were performed separately for Edgewater and Headlands Beaches.

All microbiological mean concentrations differed significantly ($P < 0.05$) for each of the three weekend collection periods at Edgewater Beach. With regard to Headlands Beach, only total staphylococci showed significantly different ($P < 0.05$) weekend mean concentrations.

Regarding day of collection (Saturday vs Sunday), there were significantly different ($P < 0.05$) mean concentrations for generally all of the microbiological variables at Edgewater Beach with the exception of total coliforms. However, at Headlands Beach only total coliforms and fecal streptococci mean concentrations were significantly different ($P < 0.05$).

As for the time of day water samples were collected, all microbiological mean concentrations except for *P. aeruginosa* were significantly different ($P < 0.05$) at Edgewater Beach. Generally highest concentrations occurred earliest in the day at 0900. At Headlands Beach, mean concentrations of total coliforms, fecal streptococci, and total staphylococci differed significantly ($P < 0.05$) by the time of day water samples were collected with highest concentrations occurring in the afternoon at 1500.

When mean concentrations for various water sampling locations were compared within a specific day and time of collection, virtually no significant differences ($P > 0.05$) were observed for all microbiological variables for either of the two beaches. The only significant differences in sampling locations were found at Edgewater Beach on Saturday at 1200 and 1500 for total staphylococci (Table 6).

In can be concluded from Tables 1-6 that in order to investigate health effects of recreational water as related to some microbiological variables, one needs to know the specific time of day and day of weekend that an individual was exposed. Differences in bacteriological indicator levels between sampling time of day and day of weekend can probably be attributed to such variables as wind direction, wind speed, wave height, precipitation, water temperature, and waste sources. Finally, virtually no significant differences ($P > 0.05$) at various locations in the bathing area were noted for the indicator variables considered in this study. The possible implication is that the water quality at these two beaches was homogeneous. This may not be the case at bathing areas having poor dispersion of fecal waste sources.

TABLE 1—Mean Total Coliform Concentration (Number/100 ml Sample with Sample Size in Parentheses) by Time of Day, Location, and Day of Weekend for Two Beaches on Lake Erie

Edgewater Beach—Cleveland, Ohio

	Time of Day															
	0900					1200					1500					
Location[a]	CK	WC	CC	EC	CL	CK	WC	CC	EC	CL	CK	WC	CC	EC	CL	Overall Mean
Saturday	17580 (3)	23306 (3)	7593 (3)	7600 (3)	19840 (3)	4407 (3)	13333 (3)	17490 (3)	10920 (3)	18050 (3)	5083 (3)	5053 (3)	10017 (3)	5916 (3)	4517 (3)	11380 (45)
Sunday	21120 (3)	9560 (3)	15078 (3)	10003 (3)	11477 (3)	7850 (3)	5459 (3)	11173 (3)	8917 (3)	6450 (3)	4390 (3)	4373 (3)	4300 (3)	3680 (3)	2873 (3)	8447 (45)
Overall Mean[b]			14316 (30)					10405 (30)					5020 (30)			

Headlands Beach—Mentor, Ohio

Location[a]	CK	WC	CC	EC	CL	CK	WC	CC	EC	CL	CK	WC	CC	EC	CL	Overall Mean
Saturday	498 (3)	397 (3)	397 (3)	322 (3)	355 (3)	227 (3)	453 (3)	180 (3)	530 (3)	177 (3)	2127 (3)	1870 (3)	1270 (3)	533 (3)	1120 (3)	697[c] (45)
Sunday	1069 (3)	91 (3)	114 (3)	79 (3)	118 (3)	237 (3)	88 (3)	249 (3)	247 (3)	45 (3)	1460 (3)	196 (3)	540 (3)	670 (3)	169 (3)	337[c] (43)
Overall Mean[b]			344 (30)					243 (30)					1008 (28)			

[a]CK: Center knee; WC: West chest; CC: Center chest; EC: East Chest; CL: Center limit.
[b]Mean concentrations at 0900 and 1200 are significantly different ($P < 0.05$) from the mean concentration at 1500.
[c]Mean concentrations for day of collection all significantly different ($P < 0.05$).

TABLE 2—Mean Fecal Coliform Concentration (Number/100 ml Sample with Sample Size Given in Parentheses) by Time of Day, Location, and Day of Weekend for Two Beaches on Lake Erie

Edgewater Beach—Cleveland, Ohio

	Time of Day															
	0900					1200					1500					
Location[a]	CK	WC	CC	EC	CL	CK	WC	CC	EC	CL	CK	WC	CC	EC	CL	Overall Mean
Saturday	2900	3102	1645	1200	3105	537	670	270	543	637	1190	1517	460	530	803	1274[c]
	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(45)
Sunday	616	212	740	782	679	657	296	418	388	72	310	294	290	570	222	436[c]
	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(45)
Overall Mean[b]			1498					449					619			
			(30)					(30)					(30)			

Headlands Beach—Mentor, Ohio

Location[a]	CK	WC	CC	EC	CL	CK	WC	CC	EC	CL	CK	WC	CC	EC	CL	Overall Mean
Saturday	56	36	41	91	31	41	20	27	43	15	53	46	34	37	28	340
	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(45)
Sunday	1029	9	31	9	18	93	14	62	51	13	183	47	262	143	86	137
	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(45)
Overall Mean			135					38					92			
			(30)					(30)					(30)			

[a]CK: Center knee; WC: West chest; EC: Center chest; EC: East chest; CL: Center limit.
[b]Mean concentration at 0900 is significantly different ($P < 0.05$) from the mean concentrations at 1200 and 1500.
[c]Mean concentrations for day of collection all significantly different ($P < 0.05$).

TABLE 3—Mean *Escherchia coli* Concentration (Number/100 ml Sample with Sample Size Given in Parentheses) by Time of Day, Location, and Day of Weekend for Two Beaches on Lake Erie

Edgewater Beach—Cleveland, Ohio

	Time of Day															
	0900					1200					1500					
Location[a]	CK	WC	CC	EC	CL	CK	WC	CC	EC	CL	CK	WC	CC	EC	CL	Overall Mean
Saturday	2807	2907	1341	1083	2836	460	650	250	503	603	1043	1370	407	510	353	1141[c]
	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(45)
Sunday	442	159	539	579	512	573	276	383	320	58	252	254	247	493	198	348[c]
	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(45)
Overall Mean[b]			1320					402					513			
			(30)					(30)					(30)			

Headlands Beach—Mentor, Ohio

Location[a]	CK	WC	CC	EC	CL	CK	WC	CC	EC	CL	CK	WC	CC	EC	CL	Overall Mean
Saturday	48	33	37	82	28	35	17	22	38	14	49	43	32	37	26	36
	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(45)
Sunday	1002	9	18	7	12	83	12	60	42	11	122	37	208	143	56	122
	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(45)
Overall Mean			128					34					75			
			(30)					(30)					(30)			

[a]CK: Center knee; WC: West chest; CC: Center chest; EC: East chest; CL: Center limit.
[b]Mean concentration at 0900 is significantly different ($P < 0.05$) from the mean concentrations at 1200 and 1500.
[c]Mean concentrations for day of collection are significantly different ($P < 0.05$).

TABLE 4—Mean Fecal Streptococcus Concentration (Number/100 ml Sample with Sample Size Given in Parentheses) by Time of Day, Location, and Day of Weekend for Two Beaches on Lake Erie

Edgewater Beach—Cleveland, Ohio

	Time of Day															
	0900					1200					1500					
Location[a]	CK	WC	CC	EC	CL	CK	WC	CC	EC	CL	CK	WC	CC	EC	CL	Overall Mean
Saturday	1328	956	608	492	952	173	300	157	183	283	227	303	257	60	50	439[d]
	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(2)	(2)	(43)
Sunday	218	109	154	147	176	154	215	152	114	158	75	297	120	242	81	161[d]
	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(45)
Overall Mean[b]			514					189					179			
			(30)					(30)					(28)			

Headlands Beach—Mentor, Ohio

Location[a]	CK	WC	CC	EC	CL	CK	WC	CC	EC	CL	CK	WC	CC	EC	CL	Overall Mean
Saturday	73	54	24	36	15	25	9	12	15	10	36	19	22	19	12	25
	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(45)
Sunday	38	15	12	5	2	102	11	44	41	18	267	86	147	143	62	66
	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(45)
Overall Mean[c]			27					29					81			
			(30)					(30)					(30)			

[a]CL: Center knee; WC: West chest; CC: Center chest; EC: East chest; CL: Center limit.
[b]Mean concentration at 0900 is significantly different ($P < 0.05$) from the mean concentrations at 1200 and 1500.
[c]Mean concentrations at 0900 and 1200 are significantly different from the mean concentration at 1500.
[d]Mean concentration for day of collection are significantly different ($P < 0.05$).

TABLE 5—Mean *Pseudomonas aeruginosa* Concentration (Number/100 ml Sample with Sample Size Given in Parentheses) by Time of Day, Location, and Day of Weekend for Two Beaches on Lake Erie

Edgewater Beach—Cleveland, Ohio

	Time of Day															
	0900					1200					1500					
Location[a]	CK	WC	CC	EC	CL	CK	WC	CC	EC	CL	CK	WC	CC	EC	CL	Overall Mean
Saturday	72	242	87	113	179	42	145	68	157	57	131	75	94	56	61	108[b]
	(3)	(3)	(3)	(3)	(3)	(2)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(2)	(43)
Sunday	28	30	28	17	38	12	34	20	21	12	13	20	21	27	8	22[b]
	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(45)
Overall Mean			83					57					50			
			(30)					(29)					(29)			

Headlands Beach—Mentor, Ohio

Location[a]	CK	WC	CC	EC	CL	CK	WC	CC	EC	CL	CK	WC	CC	EC	CL	Overall Mean
Saturday	10	2	1	2	1	5	8	3	4	4	26	7	14	91	16	13
	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(45)
Sunday	4	1	1	1	1	18	2	4	5	3	5	8	6	36	3	7
	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(45)
Overall Mean[c]			3					6					21			
			(30)					(30)					(30)			

[a]CK: Center knee; WC: West chest; CC: Center chest; EC: East chest; CL: Center limit.
[b]Mean concentrations for day of collection are significantly different ($P < 0.05$).
[c]Mean concentration at 0900 is significantly different ($P < 0.05$) from the mean concentration at 1500.

TABLE 6—Mean Total Straphylococcus Concentration (Number/100 ml Sample with Sample Size Given in Parentheses) by Time of Day, Location, and Day of Weekend for Two Beaches on Lake Erie

Edgewater Beach—Cleveland, Ohio

	Time of Day															
	0900					1200					1500					
Location[a]	CK	WC	CC	EC	CL	CK	WC	CC	EC	CL	CK	WC	CC	EC	CL	Overall Mean
Saturday	4110 (3)	3800 (3)	3427 (3)	3333 (3)	6533 (3)	5750 (3)	8393[d] (3)	3133 (3)	4933 (3)	7140 (3)	13943[e] (3)	6267[f] (3)	14300[g] (3)	18600 (3)	11666 (3)	7689[h] (45)
Sunday	1350 (2)	1200 (2)	1550 (2)	570 (2)	1125 (2)	1000 (2)	835 (2)	805 (2)	800 (2)	925 (2)	800 (2)	800 (2)	600 (2)	800 (2)	650 (2)	921[h] (30)
Overall Mean[b]			3008 (25)					3871 (25)					8065 (25)			

Headlands Beach—Mentor, Ohio

Location[a]	CK	WC	CC	EC	CL	CK	WC	CC	EC	CL	CK	WC	CC	EC	CL	Overall Mean
Saturday	947 (3)	757 (3)	563 (3)	680 (3)	857 (3)	817 (3)	793 (3)	707 (3)	857 (3)	557 (3)	1140 (3)	607 (3)	2377 (3)	1057 (3)	627 (3)	893 (45)
Sunday	770 (2)	415 (2)	200 (2)	280 (2)	520 (2)	1540 (2)	410 (2)	520 (2)	2760 (2)	1200 (2)	1210 (2)	560 (2)	750 (2)	905 (2)	470 (2)	834 (30)
Overall Mean[c]			631 (25)					962 (25)					1014 (25)			

[a]CK: Center knee; WC: West chest; EC: Center chest; EC: East chest; CL: Center limit.
[b]Mean concentrations at 0900, 1200 and 1500 are all significantly different ($P < 0.05$) from each other.
[c]Mean concentration at 0900 is significantly different ($P < 0.05$) from the mean concentrations at 1200 and 1500.
[d]WC and CC Mean concentrations at 1200 on Saturday were significantly different ($P < 0.05$) from each other.
[e]CK mean concentration at 1500 on Saturday is significantly different ($P < 0.05$) from WC and EC mean concentrations.
[f]WC mean concentration at 1500 on Saturday is significantly different ($P < 0.05$) from CC, EC and CL mean concentrations.
[g]EC and CC mean concentrations at 1500 on Saturday are significantly different ($P < 0.05$) from each other.
[h]Mean concentrations for day of collection are significantly different ($P < 0.05$).

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The Value of Human Life

It is my belief that it is unwise to emphasize the financial side of the public health question in quite the way, or quite so much, as has been done of late. Life and health are cherished by all. It needs no argument to prove that it is good to be well and that it is wise to spend money on health. It is proper to consider costs in relation to results and financial savings, when such can be figured with accuracy, but there is much in the world which cannot be measured in terms of money, though to so measure it is doubtless the tendency of the age. Should we not place our profession on a higher level by resisting this tendency instead of yielding to it? Is it not dangerous to rely upon a balance sheet of life and death when there are so many chances of error in our calculations? Is it not enough to urge expenditures for the presentation of health because the happiness of mankind will be promoted thereby?

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